SUSTAINABLE MANAGEMENT OF BASS STRAIT SCALLOPS

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The history of scallop fishing in Bass Strait, its management and research is briefly reviewed. The extent of the known biology and ecology of the species is discussed in relation to the current management of the fishery, and an assessment of the current policy is presented. Growth and recruitment overfishing as it relates to this fishery is discussed in light of the 'two spawnings' criterion underpinning the current management plan.

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Large concentrations of the 'commercial' scallop, *Pecten fumatus*, were located off Lakes Entrance in Bass Strait in 1970. Research surveys sponsored by the Tasmanian Government between 1971 and 1973 located promising scallop beds along northern Tasmania. These were first exploited in 1973, a year that saw a resurgence of fishing activity in Port Phillip Bay. Discovery of major new beds off the Furneaux Island Group in eastern Bass Strait in the late 1970s sparked off a period of rapid expansion in the scallop industry. Fishing activity in the region increased dramatically, and total landings reached a record high in 1982-83 when the total catch (live weight) approached 12,000 tonnes and the number of vessels participating tripled in two years to 231 vessels (Young & Martin,1989; Zacharin,1990).

By 1985, the main beds in Bass Strait were depleted and the decline in landings was just as dramatic as the rise. Banks Strait, the last major scallop bed in Bass Strait, was fished out during 1986. The Tasmanian zone of southern Bass Strait was closed to scallop fishing following the 1987 season, and surveys have since shown that there has been little subsequent recruitment (Zacharin,1987,1989; McLoughlin et al.,1988; Martin et al.,1989; Martin,1990).

Over this 20 year period, few, if any, commercially fished scallop beds have supported exploitation for more than 2 consecutive seasons. Few of these beds consisted of scallops comprising more than 1 or 2 year classes. The conclusion is that effort and capacity in this fishery has built up to the point that single recruitment events, resulting in discrete scallop beds of single year classes, are quickly fished out as the majority of the bed reaches a size at which they become commercially viable to land (McLoughlin et al., 1991). These beds do not, in general, appear to regenerate or provide additional year classes of scallops in the time frame of the current fishery c. 20 years.

MANAGEMENT AND RESEARCH

Zacharin (1990) and Gwyther (1990) described the management of Bass Strait scallops from both Tasmanian and Victorian perspectives. Present management resulted from concerns by State and Commonwealth Governments (and industry) following expansion during 1979–1983. The Bass Strait Interim Management Regime of November 1983 saw 97 Victorian and 134 Tasmanian based vessels gaining access to the whole Bass Strait fishery (i.e. their respective state waters and the Commonwealth controlled central zone greater than 20 nm from the coastline of the two states (Fig.1)).

The Commonwealth Government then established the Bass Strait Scallop Task Force (BSSTF), consisting of government and industry representatives, whose brief was to develop a management plan that: 1. Effectively utilised the resource; 2. Was acceptable to all parties; and 3. Was legally enforceable. The Task Force was not able to develop a management plan agreeable to all parties, and the final recommendation presented to the 1985 meeting of the Australian Fisheries Council was to effect a high degree of separation between the Tasmanian and Victorian based fleets. Access to the Commonwealth controlled central zone was restricted to scallop vessels that qualified either for a Tasmanian or Victorian state license and that had an endorsement of their Commonwealth Fishing Boat Licence. The separation was finalised under Offshore Constitutional Settlement agreements between the commonwealth and state governments

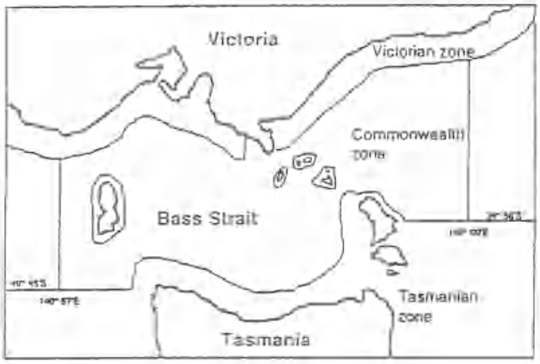

FIG. 1. Map of management zones for Bass Strait scallops. The boundaries for the two states lie 20 nautical miles offshore, with the islands belonging to Tasmania state waters.

in June 1986 (Zacharin,1990). This management plan had no biological or objective fishery management principles as its basis.

Apart from limitations on entry into the central zone fishery, no other effort or catch control regulations were imposed until June 1990, when the then Commonwealth Minister for Primary Industries and Energy, Hon. John Kerin MP, announced closure of the Bass Strait central zone to all scallop fishing. In his media release the Minister stated that he had no option but to close the area until there was clear evidence that stocks had recovered to a level which would support a sustained and substantial commercial fishery. The Commonwealth decision was (apparently) prompted by two considerations: 1. The CSIRO recommendation in early 1989 that no fishing be allowed on any of the few remaining beds in Bass Strait until stocks recovered (Fishing Industry Research and Development Corporation grant no 1985/83 final report); and 2. Reports of limited fishing on beds of apparently immature scallops in the central zone by Victorian fishermen.

Only one major study of the biology, ecology and fishery for scallops in Bass Strait has been carried out (FIRDC 1985/83). It was the final report of this study to the funding body that included a recommendation for a 'two spawnings' criterion. Regional surveys during the CSIRO study indicated severe stock depletion and a lack of recruitment (McLoughlin et al., 1988; Martin et al.,1989). The research indicated that spawning age stocks had fallen to such a low level that failure to protect existing beds could preclude recovery of scallop stocks in Bass Strait for some years.

The CSIRO study also recommended that a high priority should be to regular monitoring of the distribution and abundance of recruits and the size and condition of scallops on the few remaining beds. However this monitoring work was not carried out as it was not funded. The last survey of scallop stocks in the region was that carried out by CSIRO in May–June 1988. The decision by the Commonwealth to close the zone in 1990 was made in response to what appeared to be the imminent resumption of unregulated fishing following the collapse 3 years earlier, and concern as to the impact this might have on the recovery of scallop stocks. A bed of apparently immature scallops found near Deal Island in 1990 was surveyed in June of the same year and, despite some discussion based on interpretation of modes in the length frequency data, they were assessed by CSIRO and the Bureau of Rural Resources (BRR) as being predominately composed of 1+ year class scallops with a minor (6%) 2+ year class component (Martin 1990). It was this bed of scallops that was at risk of a resumption of unregulated fishing, and which prompted ministerial action.

In December 1990, the Commonwealth, Tasmanian and Victorian Primary Industry Ministers jointly announced a new management plan for the central zone scallop fishery; it represented a fundamental change in management philosophy (Anon. 1991). Two aspects of the new arrangements were: 1, that the Commonwealth wished to work towards handing over management to the two states, with an agreed jurisdiction line across the Strait for purposes of state fisheries administration; and 2, that opening of the central zone would be dependent upon the 'presence of commercial beds that have had the opportunity to spawn twice'.

OVERFISHING AND EXPLOITATION STRATEGIES

By the end of the 1987 season the fishery had collapsed. The total catch by Tasmanian vessels in 1987 was less than 500 tonnes, representing a 95% drop in annual landings in six years (Zacharin,1990) with Victorian vessels landing 220 tonnes, a 90% drop in catches over the same period. CPUE for the same period dropped to 13% of 1982/83 levels; industry and managers accepted that overfishing was occurring.

Although generally applicable to all fish stocks, Sinclair et al. (1985) distinguished two types of overfishing of scallops; 'recruitment overfishing' and 'growth overfishing'. The first concept invol-

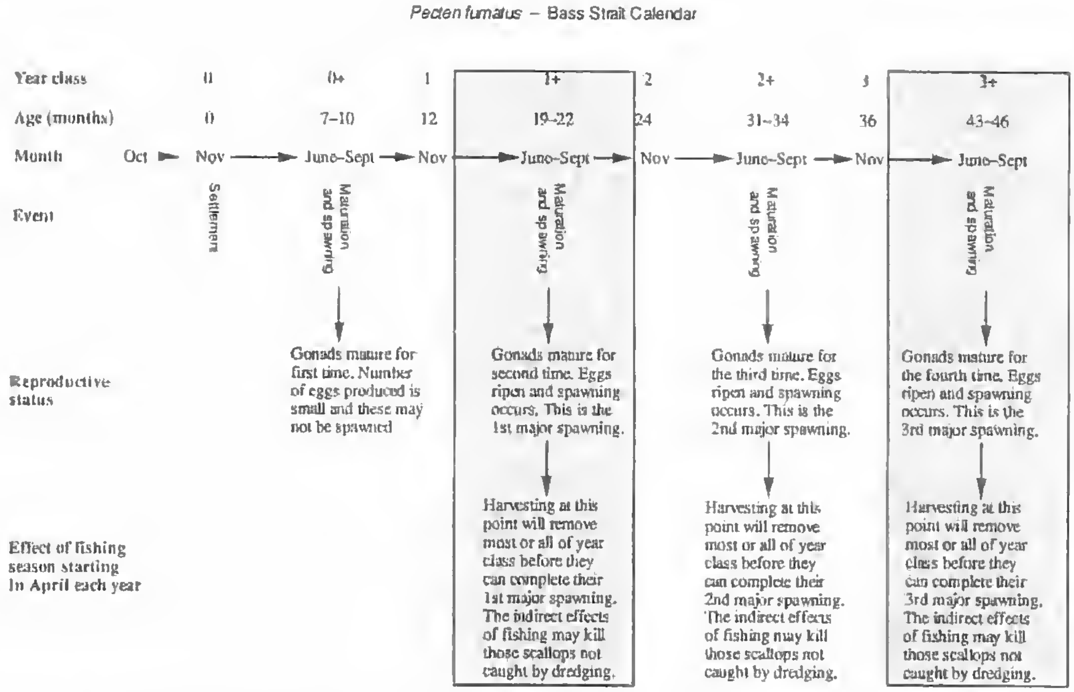

FIG.2. Biological calendar of scallop reproduction and fishing practice in Bass Strait scallops

ves the self-reproducing capacity of the population and describes a level of fishing that begins to limit the ability of the mature spawning population to effectively provide adequate future recruitment - in this case, adequate in terms of providing a commercial fishery. The second concept is relatively better understood, and describes fishing at a size or age at which the maximum yield in weight (or dollars if economic information is available) is not realized; that is, fishing the resource at a 'small' size when a larger size would provide better returns.

Having recognised the need for active management in Bass Strait, a number of strategies are worthy of consideration, including maximising yield from individual beds or populations. One approach to maximising yield from a population where annual recruitment to the same population can be ignored is to calculate the annual balance between growth of the scallops and removal from the population by death (Mohn,1986). This approach is relatively easy to evaluate given information about growth rates, mortality rates at age and the effective gear selectivity rates for each age. The problem lies in the assumptions of the 'yield-per-recruit' models used to derive this information, as they do not generally consider either environmental or fishery related variations in annual recruitment.

For example, the yield-per-recruit approach will generate the same advice on optimal fishing strategies whether or not recruitment overfishing is occurring, and yet it would be critical for a fishery manager to modify the strategies for management if such recruitment overfishing was occurring. Martin et al. (1990) examined the problems of simple yield-per-recruit management strategies for the Bass Strait scallop fishery, and concluded that they would generally provide poor results. These problems were further discussed by Young & Martin (1989).

It is still not certain whether recruitment of scallops in Bass Strait is dependent upon supply of larvae from nearby beds. However, regular spat monitoring over two years at six sites in Bass Strait, and advection modelling of larval trajectories with real wind and tide data using a verified circulation model (Fandry,1983), showed that larvae are conserved within Bass Strait in all but the windiest years (Young et al.,1992). A positive relationship between commercial catch rates and spatfall in the same 1° square in Bass Strait also provides some evidence of a stock recruitment relationship (Young et al.,1990). Thus scallop stocks are probably self-sustaining in Bass Strait and a viable spawning stock should be maintained. Although a minimum stock level cannot be defined, a conservative approach to prevent recruitment overfishing should be incorporated into the management plan. Several authors have identified the possibility of recruitment overfishing in Bass Strait (McLoughlin et al.,1988; Martin et al.,1989; Zacharin,1990; Young & Martin, 1989); the Bass Strait scallop management plan initiated in 1991 aims to avoid this problem.

AGE AND FECUNDITY

A biological 'calendar' of scallop reproduction and fishing (Fig. 2) shows that to achieve two major spawnings, scallops must be in their third year of growth. Fecundity of scallops of various ages and from various areas of Bass Strait was first determined by CSIRO during their 3 year research program (Martin et al.,1990). While fecundity was found to be variable, there appeared a relationship of size (age) and egg production, with 3+ year class scallops shedding 3–5 times as many eggs as 1+ scallops. These 3+ scallops were 75–85mm shell height. Although a linear age/fecundity schedule for Bass Strait scallops is drawn for simplicity (Fig.2) it is probable that the relationship is non-linear, reaching an asymptote at some value approximate to maximum size of this species at around 140mm shell height.

STOCK MANAGEMENT

Despite the inherent problems with the assumptions underlying yield-per-recruit models, it is useful to consider an example of growth overfishing modelled for a hypothetical Bass Strait scallop bed. Typically, the model used is an analytical yield model developed for exploited fish populations (e.g., Beverton & Holt,1957). Sinclair et al. (1985) for example, used such a model modified for use on scallops to estimate yield as a function of fishing effort and gear selectivity-at-age, where the annual catch from the population under a given fishing strategy equals the catch that can be taken from a single cohort throughout its life under the same strategy. The yield is maximised by maximising the following relationship for a single cohort,

$$Y=\int_{t-1}^{t} F_t \,.\, N_t \,.\, W_t \,.\, dt \qquad (1)$$

where Y is the annual yield, Ft is the instantaneous fishing mortality at time t, Nt is the abundance of the cohort at time t, and Wt is the meat weight in grams of the individual scallops at time t. The model assumes that fishing takes place on the same cohort over a number of years, and the management aim in this case is to target fishing on the age class (or time) when the yield is maximised. Sinclair et al. (1985) used this approach to examine the effect of varying management strategies in the Canadian fishery for the sea scallop *Placopecten magellanicus*, where up to 13 year classes may be present and fishing does not usually target on scallops until they are 5–6 years old. Their analysis showed clear overall yield benefits in targeting older year classes.

The same situation of multiple year classes and annual recruitment to beds does not occur in the Bass Strait fishery. Here, scallop beds are generally composed of a single dominant year class, are fished to 'extinction' in the same year as fishing commences, and very little survival occurs into the next year. The model does not then have to formally take into account fishing mortality in each year, since typically it is always in excess of the capacity of the bed to survive into the next year (McLoughlin et al.,1991). The model reduces to calculating the yield in each year from a given age/size structure, exploitation rate (E) and stock size (N), traded off against an annual natural mortality (M). An equation to calculate yield at time t thus reduces to:

$$Y_t=\sum E_t \,.\, N_t \,.\, W_t \qquad (2),$$

while the number of scallops available for capture in each year is

$$Nt+1 = Nt(1-M) \qquad (3).$$

This has been modelled for three management strategies, using data from average meat weights at age for Bass Strait scallops and a 'hypothetical' scallop population, where:

Nt: Although used only as an example, Zacharin (pers. comm. 1990) calculated the stock size available for capture at a bed near Deal Island as c.26 million scallops, assuming an overall 30% dredge efficiency during the survey of June 1990 (Martin,1990; McLoughlin et al.,1991). Assum-

TABLE 1. Analytical (meat) yield model results for three management strategies, where (a) is scallops fished from age 1+ onwards, (b) is scallops fished from age 2+ onwards, (c) is scallops fished from age 3+ onwards, and (d) is scallops fished from age 1+ onwards with a selectivity factor of 50% for the 1+ scallops

	Age (Yrs)	Population (000,000)	Av. Wt (g)	Catch (tonnes)
(a)	1	23.5	7.7	180.9
	2	1.5	11.2	16.8
	3	1.0	14.0	14
		TOTAL		211.7
(b)	2	12.2	11.2	136.8
	3	0.7	14.0	10.9
	4	0.5	17.0	8.5
		TOTAL		156.2
(c)	3	6.3	14.0	88.9
	4	0.4	17.0	6.8
	5	0.3	18.0	4.6
		TOTAL		100.3
(d)	1	12.2	7.7	93.9
	2	1.5	11.2	16.8
	3	1.0	14.0	14
		TOTAL		124.7

(d) modified (50%) selectivity for year 1 cohort.

ing a realistic cohort age on this bed (from length frequency data), this has been converted to an age structured population of 23.5 million 1+ year scallops (90.3%), 1.5 million 2+ year scallops (5.7%) and 1 million 3+ year scallops (4%).

Wt: While average meat weights vary significantly in Bass Strait, particularly for the King Island beds, yields are given for average meat weights for age/size classes encountered in spawning condition.

M: a fixed annual natural mortality of 0.52 has been applied to individual cohorts. While this is the only published figure for this species (Gwyther & McShane,1988), it is likely to be highly variable. This figure is used as an average value only.

The scenarios modelled under the assumptions above (Table 1) have the same population (a) fished after initial discovery as a combination of 1-, 2- and 3+ year old cohorts, (b) left for one year and fished at 2-, 3- and 4+ year old cohorts, and (c) left for two years and fished as 3-, 4- and 5+ year old cohorts. In this simple example substantial decreases in yield result from leaving the scallops until a majority are aged 2+ years and older, and this trend is continued if they are not fished until the dominant cohort is 3 years old. However, it is worth considering this result more closely in relation to actual fishing practice in Bass Strait. Scallops in year 1 cohorts in July of each year typically range in size from 50–70mm shell height, but it is unlikely that many would either be landed or processed that were smaller than about 60mm shell height (ignoring the legal minimum size limit of 70mm), thus explaining the necessity for calculation of some effective exploitation rate, E. Assuming a normal size distribution of scallops in the cohort, only one half of the cohort would then be converted to 'yield'. This has been calculated in Table 1 (d), where it is clear that yield from this bed is substantially reduced if this strategy is used, rather than leaving the bed until the major cohort was 3 years old. This size selectivity can normally be accounted for, and adjusted at will in yield models, but is kept separate here for simplicity.

Regardless of the yield implications, the important result for a management strategy utilizing scenario (b) and (c) is in potential egg production as a measure of recruitment overfishing. Using (Fig. 3):

$$\text{Fecundity (millions of eggs)} = 1.086 \text{ (years old)} + 0.148 \qquad (5),$$

it is a simple matter to calculate the difference in age-based egg production from the three management strategies (Table 1). The differences

TABLE 2. Egg production for three management strategies, based on analytical yield model of Table 1 and age/fecundity schedule of Figure 3; where (a) is scallops fished from age 1+ onwards, (b) is scallops fished from age 2+ onwards, and (c) is scallops fished from age 3+ onwards

	Age	Pop. size (000,000)	Egg production ($x10^{12}$)	Cumulative egg production
(a)	1	23.5	29	
	2	1.5	3.5	
	3	1.0	3.4	
		TOTAL	35.9	35.9
(b)	2	12.2	28.3	
	3	0.8	2.6	
	4	0.5	2.2	
		TOTAL	33.2	69.1
(c)	3	6.3	21.6	
	4	0.4	1.8	
	5	0.3	1.4	
		TOTAL	24.8	93.9

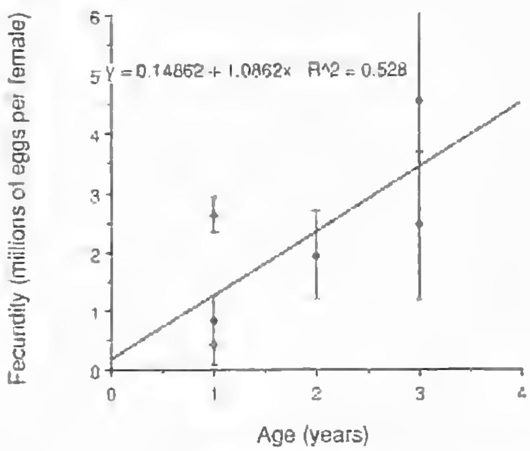

FIG. 3. Age (years) versus fecundity for six Bass Strait scallop beds.

in egg production from these strategies are evident from Table 2, where it is obvious that while most eggs are released when population size is at its highest, removing the population at this point will result in only a fraction of the total egg production that would have been realised if the population had been left until the major cohort was 3 years old, that is, the population spawns in each year of the three years until caught.

The difference in moving from management strategy (d) to strategy (c) will result in only a 20% drop in total yield, but a 260% increase in egg production. Over the medium to long term it is probable that this will be reflected in the recruitment strength of scallop stocks, as well as in higher overall prices from larger sized scallops.

DISCUSSION

Given the high per-unit value and the relative ease of catching scallops when they are abundant, it is hardly surprising that continued consumer demand has had a significant impact on investment and effort in the Bass Strait fishery. Other complicating factors include 'diversified' fishing license policies in Tasmania, which maintains a large pool of potential effort, and conversely, the lack of diversified license policies in Victoria which forces effort into the fishery because of the inability of the licence holders to spread effort to other fish stocks. There is no easy management solution here, but is becoming evident that there is a need for bioeconomic modeling to determine not only effects of ecological and environmental variables on scallop stocks, but also the critical problems of social and economic pressures on the scallop fishing industry and how these relate to stock management (Caddy,1989).

A structural problem in the Bass Strait fishery is that these same social and economic pressures, and a lack of management foresight in the late 1970's and early 1980's, have resulted in a fleet capable of annual overfishing of available stocks. The management plan introduced in 1991 contains a mechanism for avoidance of the most serious long term problem, recruitment overfishing. The two spawnings criterion goes a long way to solving this chronic overfishing problem while also attempting to maximise the yield from existing recruits, but the economics of fishing will remain marginal while stocks remain low. This linking of 'yield-per-recruit' with 'eggs-per-recruit' is a valuable extension of the analytical yield model and was used by Mohn et al. (1984) to develop management strategies for Georges Bank scallops (Gabriel et al.,1989). The mechanism for achieving the two spawnings policy, that is, a trashing rate tied to a size limit, does not reduce its medium and long term validity and is also a valuable management tool for conservation of juvenile stocks. The trashing rate concept will also become increasingly important as (hopefully) stocks rebuild and new juvenile beds are discovered.

Similar policies for shifting fishing effort from younger age groups to older and larger age groups have resulted in substantial gains in long term yields and egg production in Canadian scallop fisheries (Caddy,1989). Targeting of older age group scallops had a number of beneficial impacts on fishing strategies not characteristic of simple minimum size limits, which has been suggested as an alternative policy for the Bass Strait fishery. A minimum size limit without a viable system of protecting dense patches of new recruits by local area closures (particularly in multiple year class beds) would return the fishery to the destructive practice of fishing areas of predominately small shell in order to cull out the few large scallops, while inflicting high levels of incidental mortality on unlanded juveniles (McLoughlin et al.,1988; Caddy,1989). The fact that this practice does occur at low stock levels in Bass Strait is evident from examination of the 1987 season (Martin et al.,1989).

The principle of the 'two spawnings' criteria is nothing more or less than one strategy for stock rebuilding. However, a stock rebuilding strategy, with the specific objective of increasing spawning stock abundance, is just one example of a fishery management strategy (Sainsbury,1992a). The management strategy may include the use of biological or fishery reference points and a specified way in which the reference points are to be used in the management of the fishery (e.g. no fishing on stocks until they have completed two spawnings). However, as Sainsbury (1992a) explained, the essential point is that the management strategy to be evaluated is but one aspect of a process that includes stock dynamics, economic dynamics, observations (of fleet and fishery performance), estimation procedures, management decisions and management implementation, all operating under a management policy with specific goals or objectives.

The exact causes and mechanisms of recruitment collapse are poorly known, although often a combination of high fishing mortality and environmental variability is indicated, and ecological interactions are suspected. The complexity of these interactions is such that there is little expectation that the population size at which recruitment collapse will happen can be accurately predicted (Sainsbury,1992b). However, recruitment collapse has occurred in numerous marine resources, and it is strongly suspected in Bass Strait scallops from 1986-1990.

Ultimately, the reliability and success of any management strategy (for Bass Strait scallops) is seen to be dependent on the ability to forecast accurately (Mohn,1986), although this may require a long time series of catch data to be reliable (Orensanz et al.,1991). However, with large interannual fluctuations in recruitment, growth and mortality typically occurring in Bass Strait scallops such a predictive capability is not yet possible. Management must therefore rely on maximising probability for both maximal annual yield and recruitment success in subsequent years, and these strategies must be maintained over a suitable time period to determine if they are successful.

In respect of Bass Strait scallops, the current management strategy is a stock rebuilding strategy based on output controls: two spawnings based on an average size at age, and catch restrictions, unrelated to stock size but implemented for orderly marketing and processing. However, there remains the risk that the underlying structural problems remain unattended. These are, critically, (1) overall fleet size, and (2) a lack of knowledge of stock size, resilience and productivity. The lack of a link between annual total catch and stock size is particularly worrisome as none of the usual stock management strategies linking catch and stock, such as proportional escapement, constant escapement or proportional harvesting rate can be, or are, being applied. What is being applied is a constant quota which is generally recognised as a high risk strategy since it ignores interannual recruitment variability. For example, one possible scenario is that even with a two spawnings strategy, three adverse years of environmental conditions for recruitment will see all stocks (beds) available for fishing, and with the existing excess fishing capacity and with annual natural mortality, stock collapse would be once again a real possibility. Further, the existing management plan theoretically allows approximately 18,000 tonnes of scallops (live weight) to be landed in any year (ie., No. of vessels in fleet x monthly quota x no. of months available for fishing), despite the knowledge that in the history of the fishery no more than 12,000 tonnes has been landed in any one year.

What then might be a course of action for considering these problems ? Initially, an assessment of the existing policy with regards to stock recovery will be necessary. Assuming that the stock does recover to some level consistent with a more constant level of annual recruitment, then in the medium term a linking of annual catch with stock size will become necessary for some level of sustainability (that is, an estimate of minimum spawning stock biomass-per-recruit). Of course, this is inextricably linked with profitability for the fleet, with the economics of fishing for the existing fleet only being viable at relatively high stock sizes - financial viability at lower stock sizes will rely on the reduced catch being shared among fewer operators. A policy objective in the medium term may well be an appropriate reduction in fleet size to a level at which economic viability is maintained at average annual catches.

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